

Infrasonic Tracking of Wake Vortices

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NASA Aeronautics Research Mission Directorate (ARMD)

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Outline

- ➤ The Innovation
- > Technical Approach
- > Impact
- > Results
- **Conclusions**
- > Next Step



The Innovation

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Objective

- Tracking of aircraft wake vortices during takeoff and landing from their infrasonic emissions

Innovation

- System* for tracking aircraft wake vortices during takeoff and landing.

*

- 1. US Patent Number 8,401,207, "Extreme Low Frequency Acoustic Measurement System"
- 2. "Wind noise reduction in a non-porous subsurface windscreen" Zuckerwar et al.,164th Meeting of the Acoustical Society of America October 22, 2012



Theoretical Motivation

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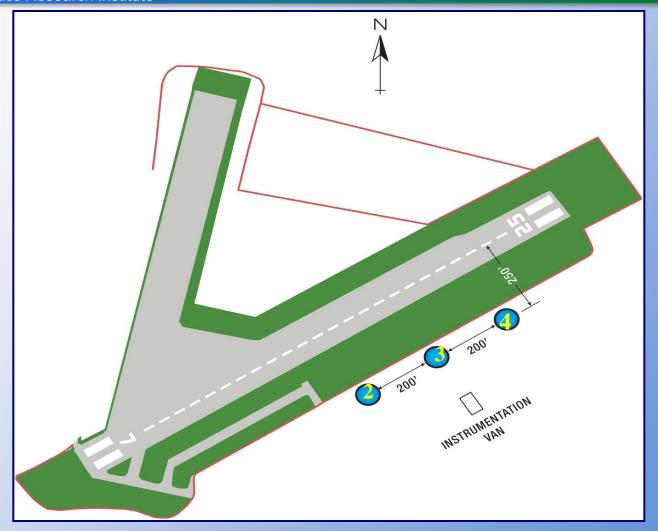
 Several possible mechanisms of aircraft vortex sound generation were examined by Hardin and Wang*

 The most robust mechanisms result in very low frequency sound

^{*}Jay C. Hardin and Frank Y. Wang (NASA/CR-2003-212674)



Microphone Array Installation at PHF





Microphone inside sub-surface windscreen

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Microphone specs:

Frequency Range DC to 500 Hz Sensitivity(± 2 dB) 400 mV/Pa Windscreen Transmission:

0 - 100 Hz

Q.A. Shams, A.J. Zuckerwar, C.G. Burkett, G.W. Weistroffer, and D.K. Hugo, "Experimental investigation into infrasonic emissions from atmospheric turbulence," J. Acoust. Soc. Am. 133, 1269-1280 (2013).



Data Acquisition System

- B&K 4-channel PULSE system is being used for data acquisition.
- B&K "Labshop" analysis platform
- Output
 - Time history
 - Spectra
 - Coherence



Bruel &Kjaer 4-ch Input Module LAN-XI 51.2kHz



Field Calibration



- Infrasonic pistonphone
- 80 dB at 14 Hz



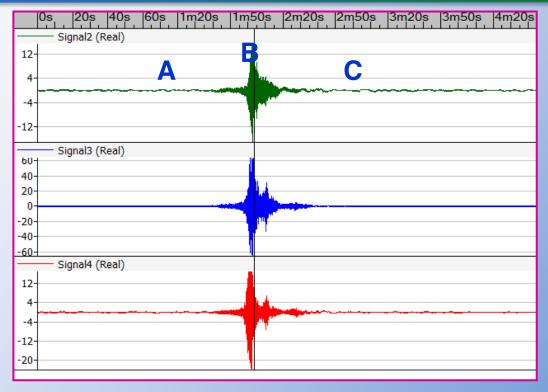
Impact

- Currently minimum spacings between aircraft as high as three minutes
- These spacing are overly conservative most of the time
- If spacing could be reduced by 30 seconds during high airport traffic periods, projected airline savings is more than \$5B per year
- Our innovation will reduce the spacing



Results: Time History

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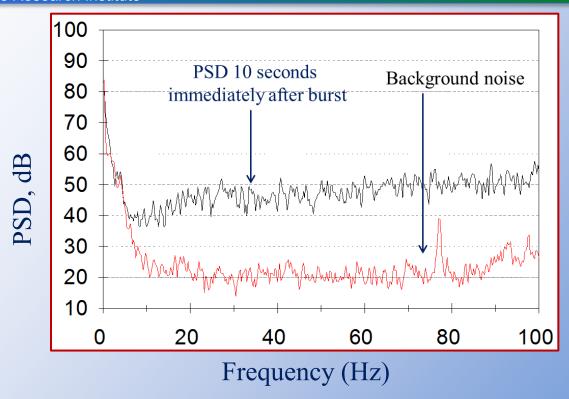
The pressure signals received at the three microphones fall into three regions (A, B, & C). On takeoff: Region A: Aircraft is accelerating toward takeoff.

Region B: Aircraft passes microphones and takes off, producing large hydrostatic pressure, called a "burst," which serves as a reliable time stamp. Region C: Aircraft is airborne, shedding wake vortices.



CRJ Takeoff auto-spectrum (Channel 2)

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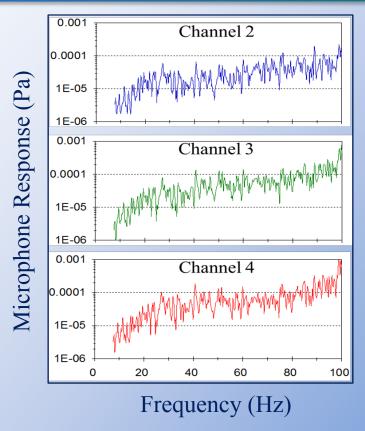


The microphone signals 10-s after takeoff (coherent) are more than 20 dB above the background (incoherent). Since the vortex emission spectrum appears similar to the background spectrum, we concluded that coherence is a better indicator of vortex presence than spectral level. The spectrum is broadband and reveals no features.



Autospectrum for each channel

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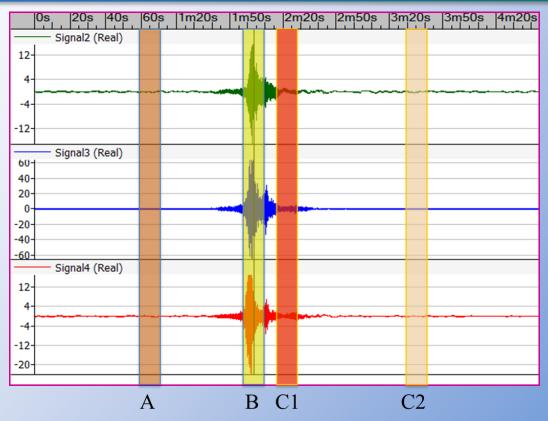


This slide shows the wake vortex emission spectrum on each microphone channel. The data reveals that the spectrum is the same on all three channels, thus the vortex emissions are radial.



10 seconds intervals prior and after takeoff CRJ Takeoff

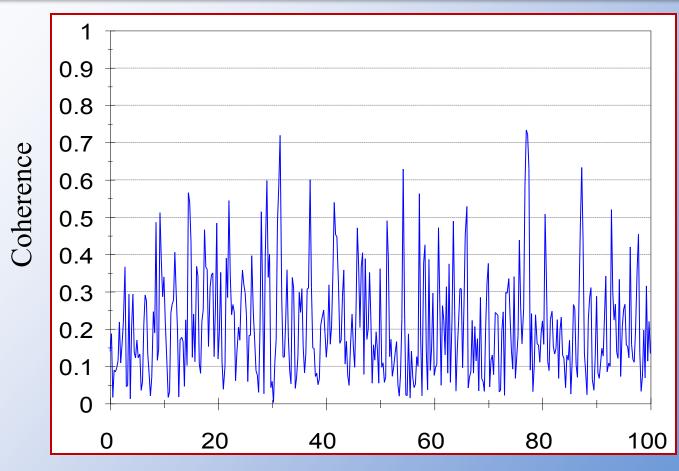
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In this slide, the coherence spectrum on takeoff of CRJ is examined in 10-s intervals: prior to burst (brown), at instant of takeoff (burst, yellow), 10-s after takeoff (red), and 50-s after takeoff (amber).



CRJ Takeoff Prior to burst – Region A

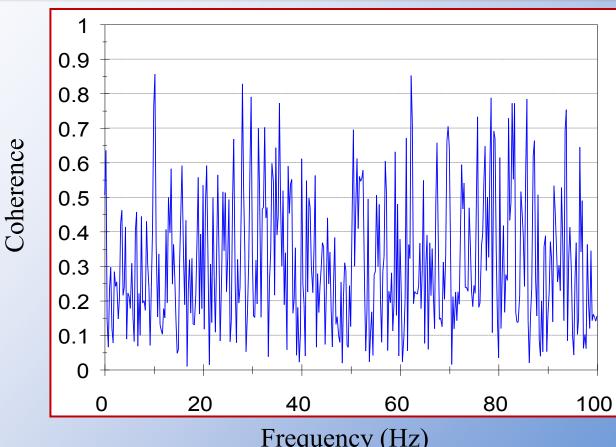


Frequency (Hz)



CRJ Takeoff during burst – Region B

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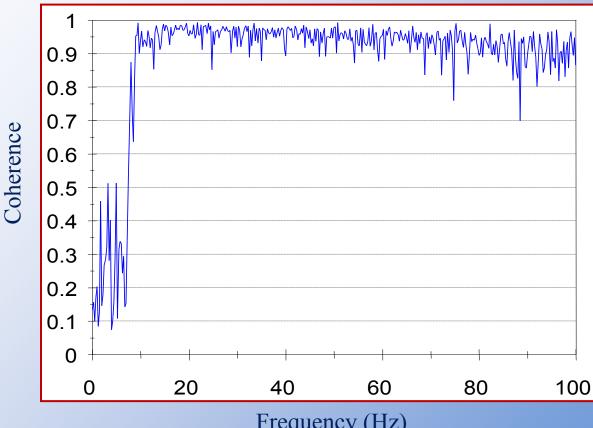
Frequency (Hz)

The pressure bursts have low coherence, hence are non-propagating and hydrostatic in nature.



CRJ Takeoff immediately after burst – C1

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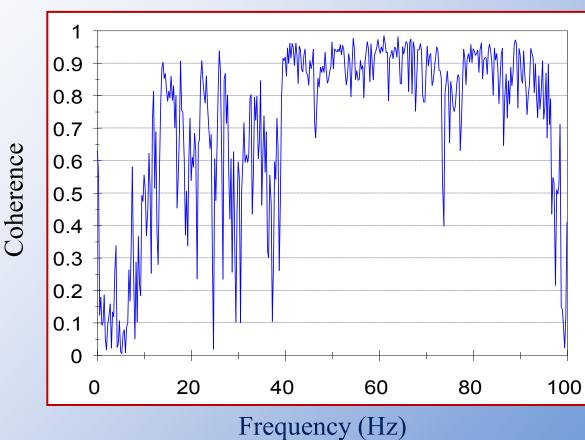
Frequency (Hz)

The high coherence spectrum immediately after takeoff indicates strong emissions from wake vortices.



CRJ Takeoff 50 s after burst – Region C2

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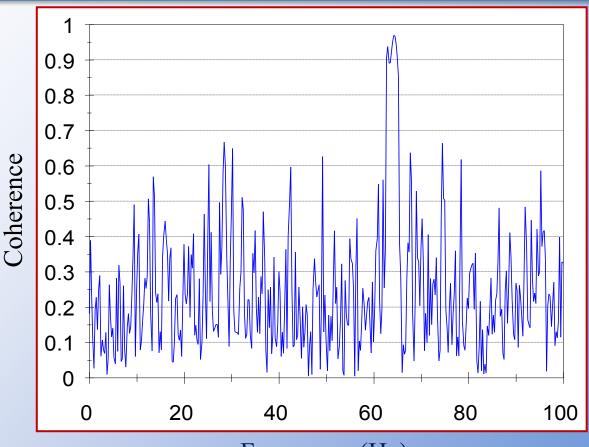


A lower coherence indicates the weakening of the vortex emissions.



CRJ Takeoff 90 s after burst

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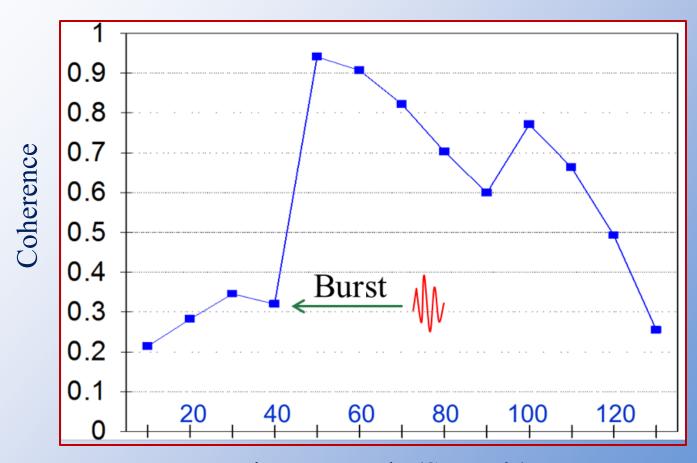


Frequency (Hz)

A low coherence indicates the complete dissipation of the wake vortices.



CRJ Takeoff Coherence Time History Mean 10-70 Hz

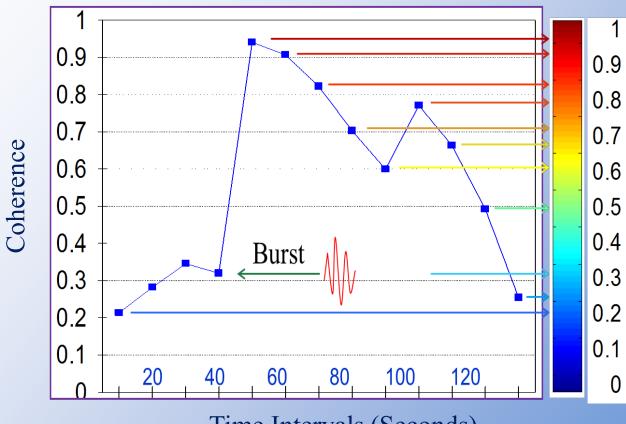


Time Intervals (Seconds)



Coherence color coding

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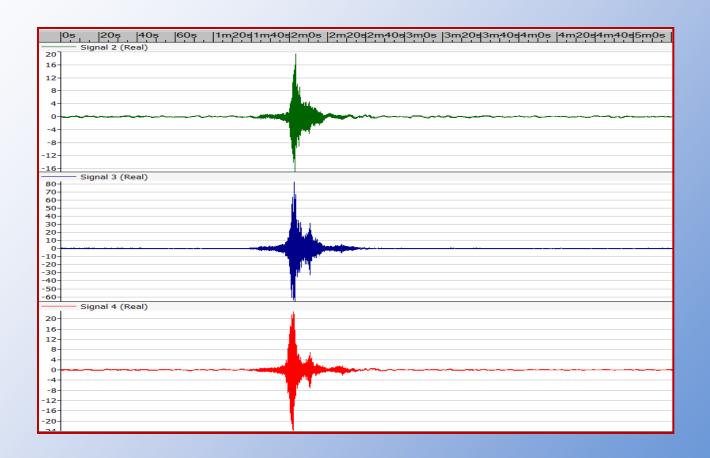


Time Intervals (Seconds)

The plots of coherence time history are color-coded according to the scale shown (red = high coherence, blue = low coherence)

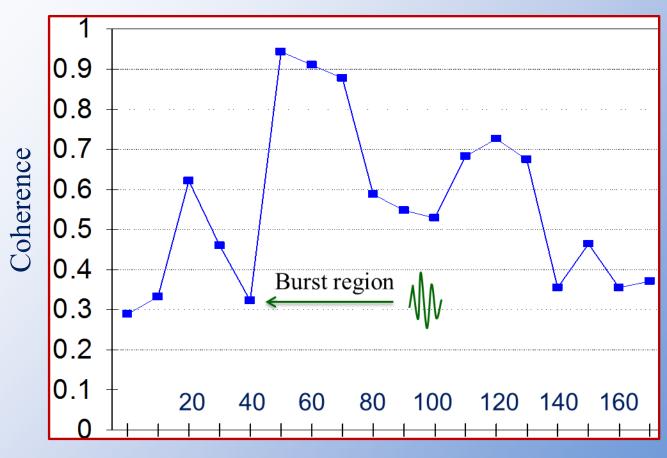


Pressure Bursts during MD-88 Takeoff





MD88 Takeoff Coherence Time History Mean 10-70 Hz



Time Interval (Seconds)



Pressure bursts of Region B

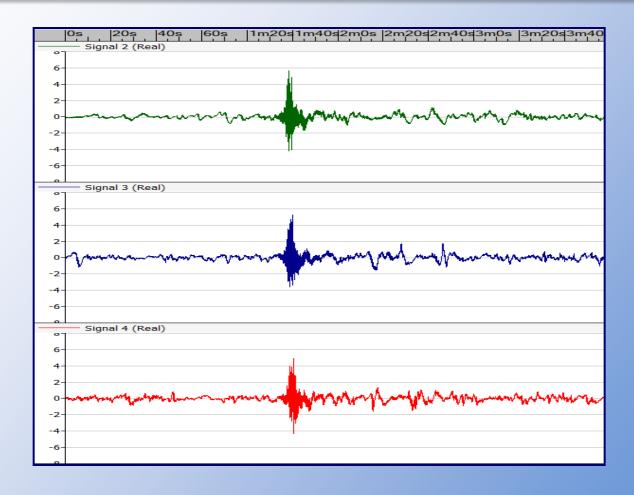
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Aircraft passes microphones producing large hydrostatic pressure few seconds prior to takeoff.

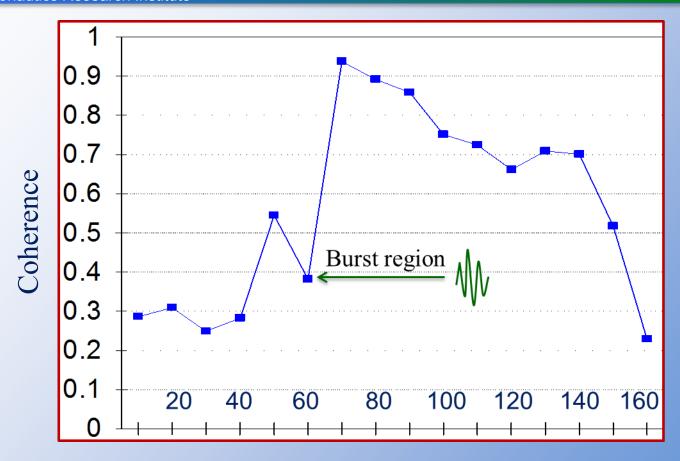


Pressure Bursts during Airbus-319 Takeoff





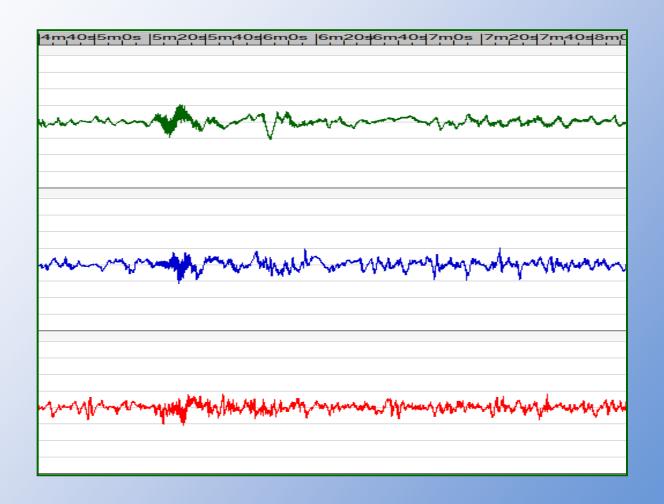
Airbus Takeoff Coherence Time History Mean 10-70 Hz



Time Interval (Seconds)

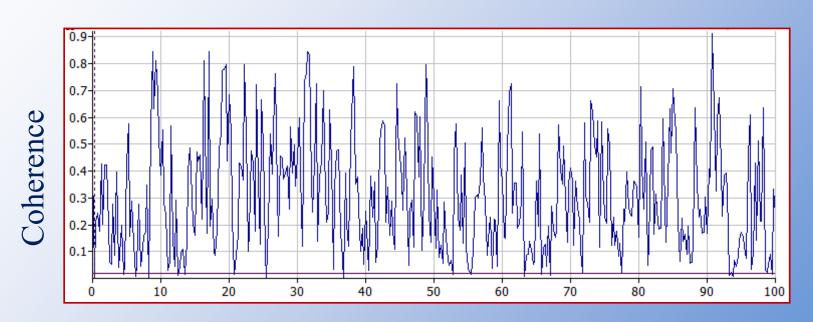


Pressure Bursts at Landing of Airbus-319





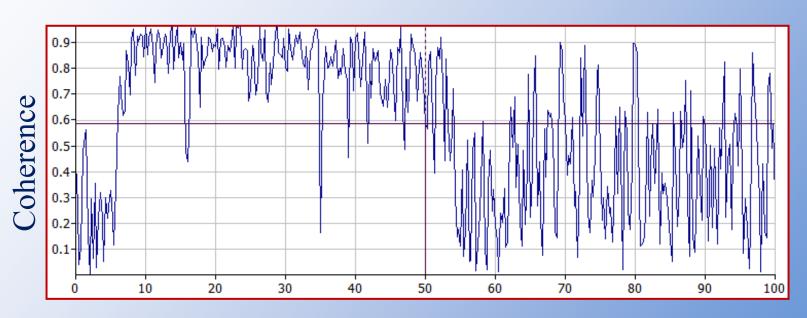
30 seconds before Landing (Airbus 319)



Frequency (Hz)



20 seconds before Landing (Airbus 319)



Frequency (Hz)



Summary Chart

(Coherence time histories)

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The slide shows the coherence time histories of wake vortex emissions for various aircraft on takeoff and landing. The sequence of low-coherence, burst, high coherence has been observed on all takeoff and landing events without exception.



Conclusions

- 1. Wake Vortex emission spectra are broad band.
- 2. Cross-spectral coherence has proved an effective designator for tracking time history.
- 3. The pattern of pressure burst, high coherence intervals, and diminishing-coherence intervals was observed for all take-off and landing events without exception.
- 4. The appearance of pressure bursts when aircraft pass microphones has never been reported before. They serve a reliable time stamp.
- 5. Measurements exceeded expectations



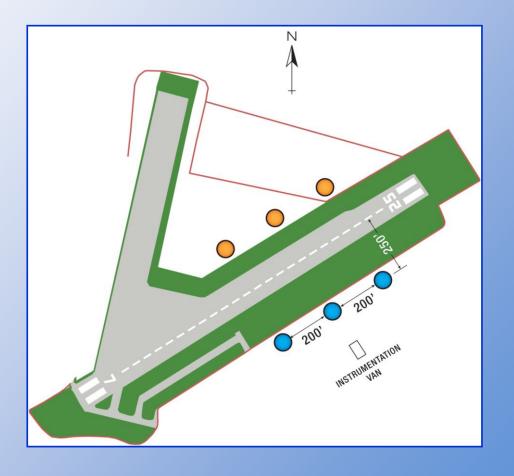
Distribution/ Dissemination

- 166th Meeting of Acoustical Society of America (Dec. 2-6, 2013)
 - Infrasonic emissions from aircraft wake vortices: field installation
 - Infrasonic emissions from aircraft wake vortices: experimental results
- 20th AIAA Aeroacoustics Conference (16 20 June 2014) Atlanta, Georgia
 - Title to be determined



Next Steps

- Take steps to determine location of wake vortices
- Purpose: to locate wake vortex pair





Next Steps

- Install weather station to determine impact of wind on movement of wake vortices
- Expand data base to obtain reliable statistics
- Transfer of data 6000 feet through optical fiber for real time display
- Current TRL is 5, At the end of phase II TRL will be 6 or higher